GPU-Enabled Debris Disk Modeling with GRaTer-JAX

A Uniform Analysis of Gemini Planet Imager H-Band Polarimetric Data

Briley L. Lewis, Mihir Kondapalli, Maxwell A. Millar-Blanchaer, Jaren Ashcraft

University of California, Santa Barbara

What's a debris disk, and what does it tell us about planets?

- **Debris disks** are belts of dust, replenished by collisions between planetesimals — like our solar system's asteroid and Kuiper belts.
- They're found around older stars (>10 Myr), after the earlier gas-rich protoplanetary disk stage.
- They give insight into planetary *evolution* (e.g. the Late Heavy Bombardment) and provide a window into grain properties, helping constrain planet *formation* models

Why should we use GPUs to model debris disks?

- Debris disk modeling is very computationally expensive, so traditionally we have had to make many assumptions in models / couldn't fit for all the parameters we would like to
- New tools can help us speed things up: GPU computation, automatic differentiation, just-in-time (JIT) compilation

We developed the GRaTer-JAX package (based off the GRaTer models in Augereau+ 1999) for faster debris disk modeling, and can now fit for more parameters in record time!

What did we find when we applied GRaTer-JAX to GPI data?

- We modeled a large sample of disks imaged in H-band polarimetry with the Gemini Planet Imager (GPI) [Fig. 1]
- These fits revealed surprising trends in disk morphology, like the flaring parameter β [Fig. 2], which was previously assumed to be 1 or 2 [Fig. 3]
- We also fit for the *scattering phase function*, a measure of how efficiently light is scattered at different angles by the dust grains, related to composition [Fig. 4]

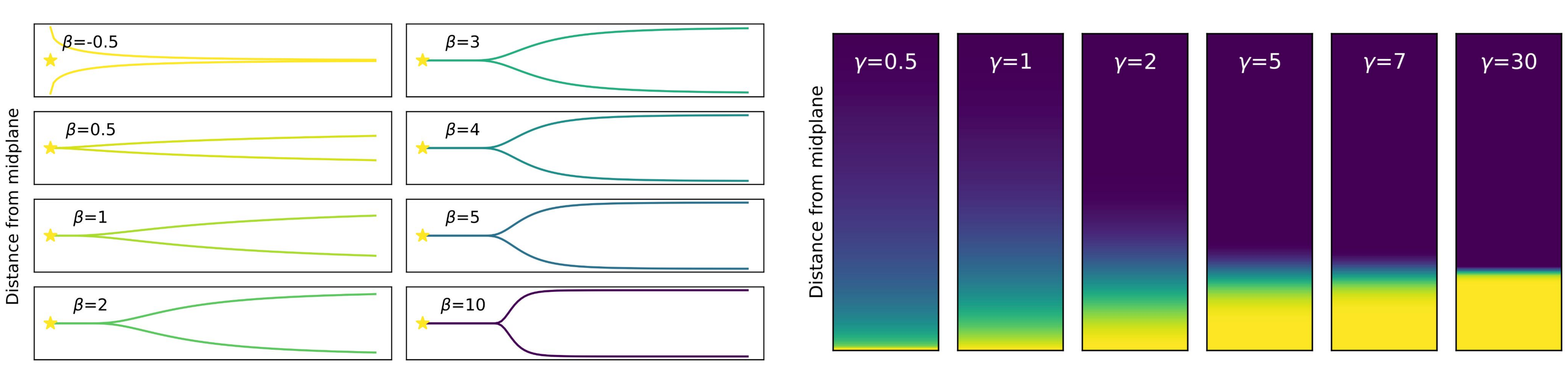

Figure 2: (Left) An illustration of how the flaring parameter β changes the profile of a disk. (Right) An illustration of how the decay exponent γ changes the vertical profile of a disk. Neither of these parameter has been explored much with previous work due to computational limitations.

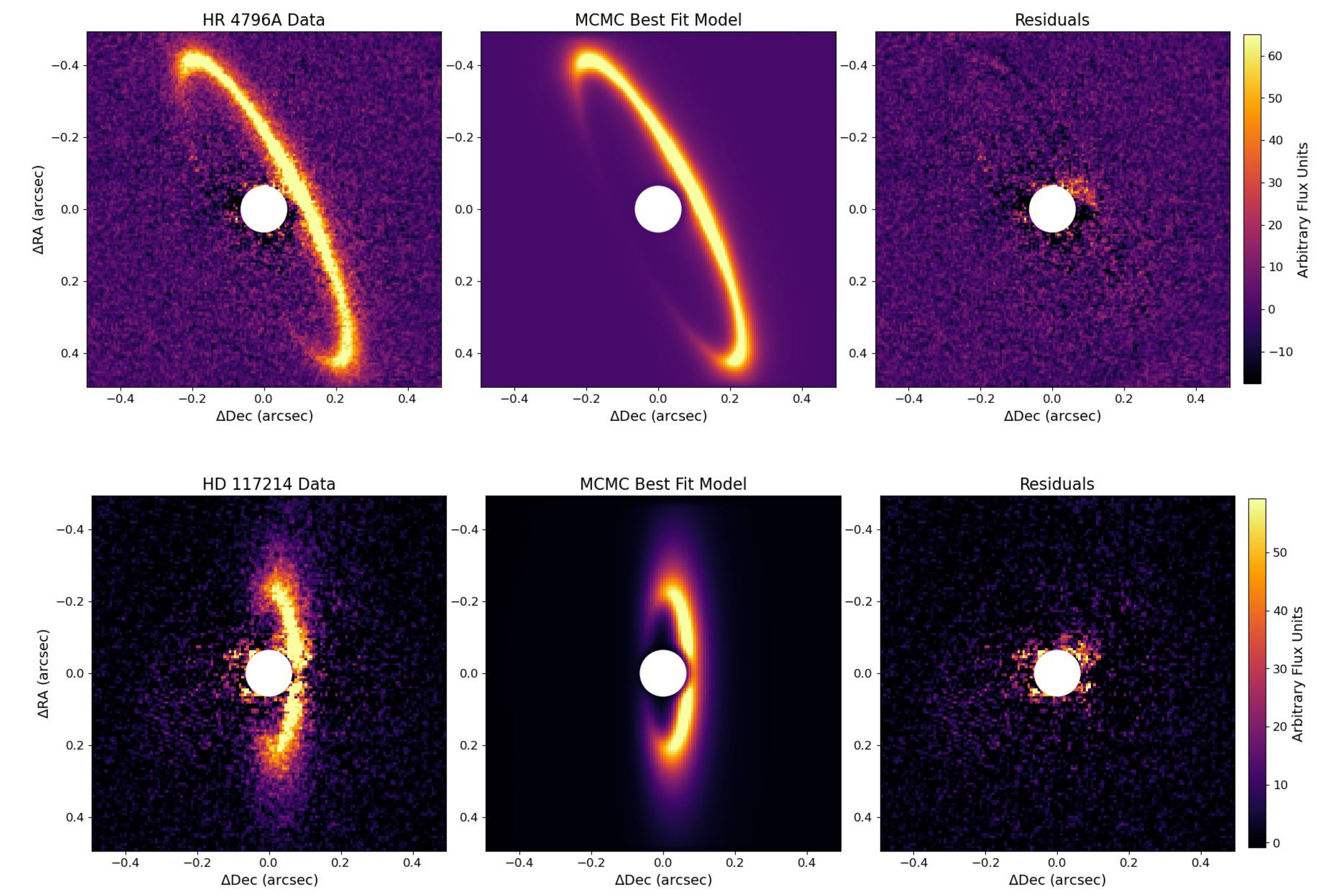

Figure 1: Two debris disks imaged by GPI and modeled using GRaTer-JAX, with data (left), best-fit model (center), and residuals (right). We fit for >10 parameters using MCMC, and the wall-clock computation time was under 12 hours—a vast improvement on past modeling tools.

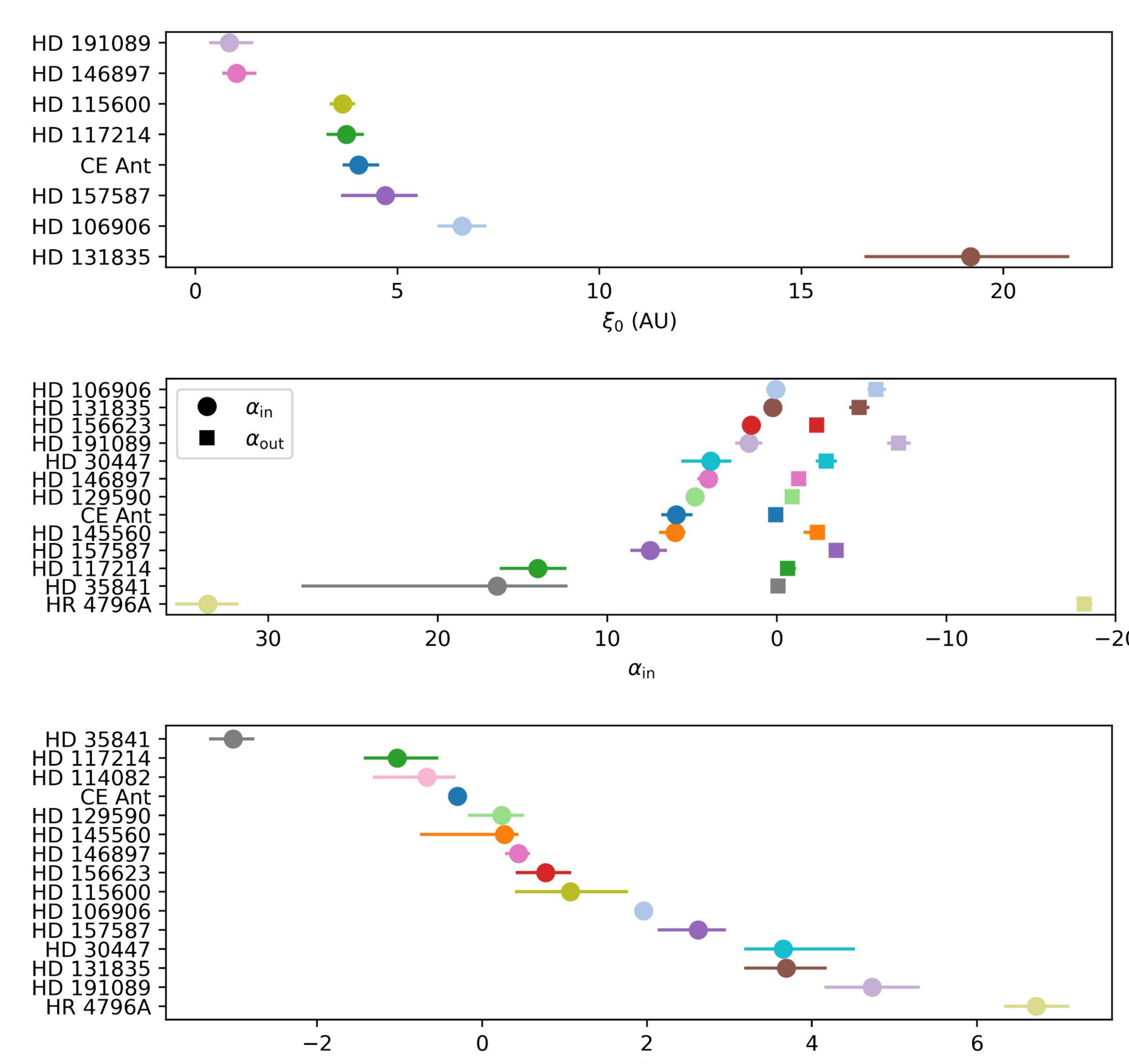

Figure 3: Four disk morphology parameters as fit by GRaTer-JAX. (Top) The scale height, ξ_0, shows small variation and one outlier. (Middle) Inner and outer density power law exponents, α_{in} and α_{out}, where HR 4796A is a distinct outlier. (Bottom) The flaring parameter β, traditionally assumed to be 1 or 2, shows substantial unexpected variation across the sample.

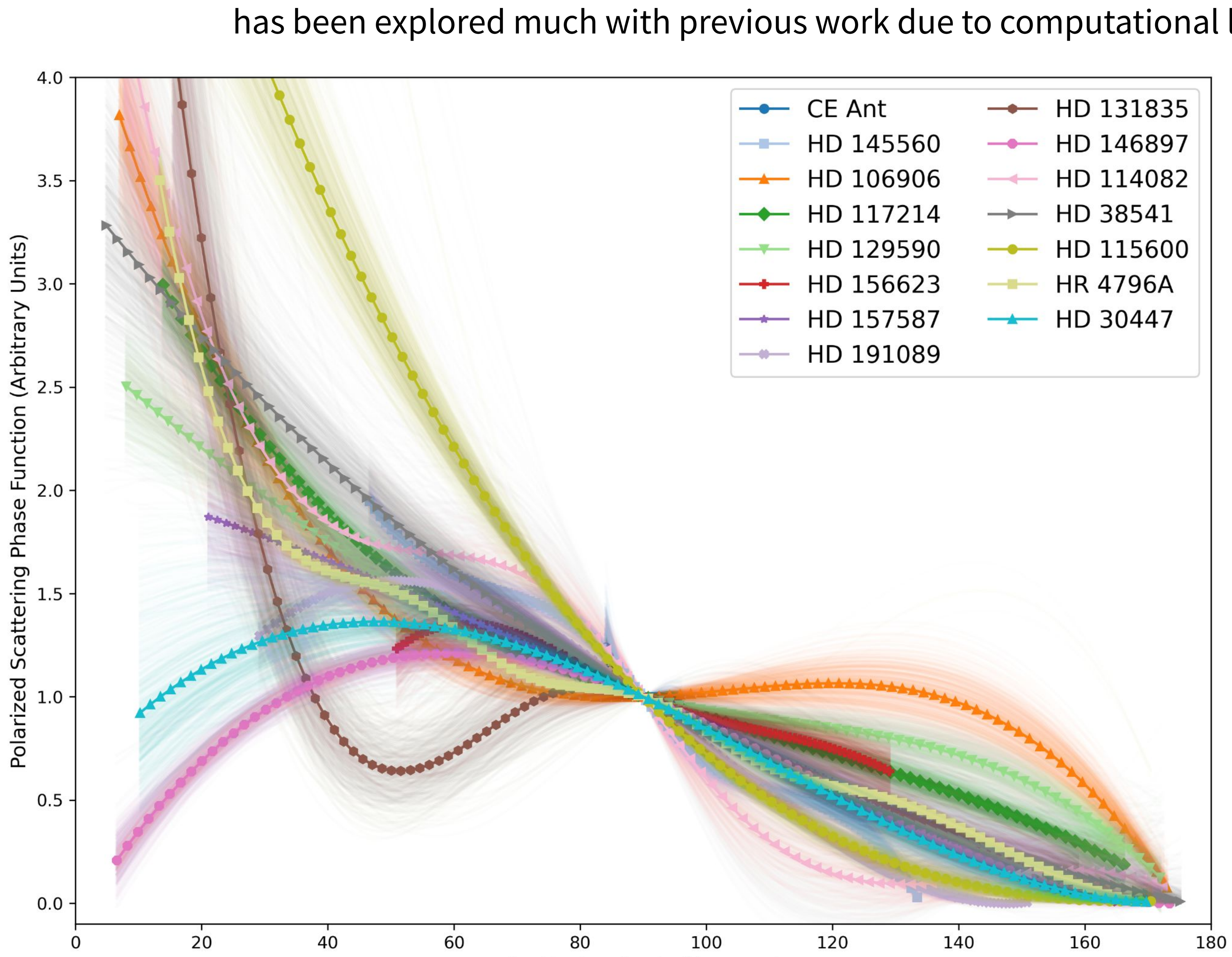

Figure 4: Spline scattering phase functions for all disks modeled. A majority appear similar within error bars, suggesting common composition/grain properties.

Main Takeaways

- We have a new modeling tool, **GRaTer-JAX**, that takes advantage of AI/ML tools like JAX (automatic differentiation, JIT compilation, GPU computing) to make debris disk models significantly faster
- Analysis of GPI disk imaging data shows some surprising trends worthy of further investigation, like highly varied disk morphology (e.g. the flaring parameter β)
- Best fit scattering phase functions are quite similar, suggesting a common composition / grain properties

Check out the code here!